Preschool Predictors of Mathematics in First Grade Children with Autism Spectrum Disorder

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Abstract

Up till now, research evidence on the mathematical abilities of children with autism spectrum disorder (ASD) has been scarce and provided mixed results. The current study examined the predictive value of five early numerical competencies for four domains of mathematics in first grade. Thirty-three high-functioning children with ASD were followed up from preschool to first grade and compared with 54 typically developing children, as well as with normed samples in first grade. Five early numerical competencies were tested in preschool (5-6 years): verbal subitizing, counting, magnitude comparison, estimation, and arithmetic operations. Four domains of mathematics were used as outcome variables in first grade (6-7 years): procedural calculation, number fact retrieval, word/language problems, and time-related competences. Children with ASD showed similar early numerical competencies at preschool age as typically developing children. Moreover, they scored average on number fact retrieval and time-related competences and higher on procedural calculation and word/language problems compared to the normed population in first grade. When predicting first grade mathematics performance in children with ASD, both verbal subitizing and counting seemed to be important to evaluate at preschool age. Verbal subitizing had a higher predictive value in children with ASD than in typically developing children. Whereas verbal subitizing was predictive for procedural calculation, number fact retrieval, and word/language problems, counting was predictive for procedural calculation and, to a lesser extent, number fact retrieval. Implications and directions for future research are discussed.

Keywords: autism spectrum disorder; early numerical competencies; first grade mathematics

1. Introduction

Autism spectrum disorders (ASD) are characterized by persistent deficits in social communication and social interaction, together with restrictive, repetitive patterns of behaviour, interests or activities (American Psychiatric Association [APA], 2013). Despite the predominant clinical focus on the social-communicative impairments in children with ASD, interest in the academic functioning of these children has grown more recently (Tincani, 2007; Whitby & Mancil, 2009). Indeed, when tackling the issue of educational inclusion of children with ASD, it is important to gain insight into their academic strengths or needs. Even though a large part of children with ASD are defined as "high-functioning" (i.e., displaying an IQ score of at least 70), appropriate support or accommodation might still be needed to reach their full potential (Whitby & Mancil, 2009). Regarding the field of mathematics, teachers and therapists often consider mathematics as one of the difficult subject matters for children with ASD (Department for Education and Skills, 2001; van Luit, Caspers, & Karelse, 2006). However, the amount of research on this topic does not match their concern. Not only are studies on mathematics in children with ASD scarce, the few existing studies focus on different aspects of the topic: mathematical processes (e.g., Gagnon, Mottron, Bherer, & Joanette, 2004) versus mathematical outcomes (e.g., Chiang & Lin, 2007) or within-group (mathematical abilities relative to own cognitive abilities; e.g., Mayes & Calhoun, 2003) versus between-group (mathematical abilities of children with ASD compared with typically developing children; e.g., Iuculano et al., 2014) analyses or comorbidity studies (e.g., Mayes & Calhoun, 2006). When consulting existing literature, two opposite views emerge. First of all, anecdotal and descriptive research (Baron-Cohen, Wheelwright, Burtenshaw, & Hobson, 2007; Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001; Sacks, 1986) as well as some empirical studies (Iuculano et al., 2014; Jones et al., 2009) have put forward that children with ASD show enhanced mathematics compared to their typically developing (TD) peers. In contrast, other empirical studies such as comorbidity studies (Mayes & Calhoun, 2006; Reitzel & Szatmari, 2003) and some within-group studies (Chiang & Lin, 2007; Mayes & Calhoun, 2003) suggest mathematical problems in children with ASD.

A limitation of the aforementioned research is the cross-sectional nature of these studies (e.g., Iuculano et al., 2014; Jones et al., 2009; Mayes & Calhoun, 2003). Recently, a longitudinal study examined the reading and mathematics profiles and their growth trajectories in children with ASD (Wei, Christiano, Yu, Wagner, & Spiker, 2014). However, despite the identification of several early numerical competencies of preschoolers as strong predictors of later mathematical abilities (e.g., DiPema, Lei, & Reid, 2007; Duncan et al., 2007; Kroesbergen, Van Luit, & Aunio, 2012; Locuniak & Jordan, 2008), the predictive value of these early numerical competencies for later mathematical abilities in children with ASD remains unexplored as yet.

1.1 The Importance of Early Numerical Competencies for Later Mathematics

Jordan and Levine (2009) identified five early numerical competencies, namely verbal subitizing, counting abilities, magnitude comparison, estimation, and arithmetic operations. *Verbal subitizing* can be described as the rapid (40-100 ms/item), automatic and accurate enumeration of small quantities of up to three (or four) items (Kaufman, Lord, Reese, & Volkmann, 1949). Several studies demonstrated that subitizing is an important factor in mathematical development (Landerl, Bevan, & Butterworth, 2004; Penner-Wilger et al., 2007; Traff, 2013), and longitudinal research demonstrated that subitizing is a domain-specific predictor for later mathematical performance over and above domain-general abilities (Krajewski & Schneider, 2009; Kroesbergen, Van Luit, Van Lieshout, Van Loosbroek, & Van de Rijt, 2009; LeFevre et al., 2010; Reigosa-Crespo et al., 2012). *Counting* has also proven to be of central influence for the development of adequate mathematical abilities (Aunola, Leskinen, Lerkkanen, & Nurmi, 2004; Fuson, 1988; Le Corre, Van de Walle, Brannon, & Carey, 2006; Passolunghi, Vercelloni, & Schadee, 2007; Wynn, 1990). Whereas procedural counting knowledge (the ability to perform a counting task) has proven to be predictive for numerical facility, conceptual counting knowledge (the understanding of why a procedure works or is legitimate) is predictive for untimed mathematical achievement (Desoete, Stock, Schepens, Baeyens, & Roeyers, 2009; LeFevre et al., 2006). *Magnitude comparison* is the ability to discriminate two quantities in order to point out the largest of both (Gersten et al., 2012). Although number comparison has proven to play an important role in the development of mathematical abilities (De Smedt, Verschaffel, & Ghesquiere, 2009; Holloway & Ansari, 2009; Jordan, Glutting, & Ramineni, 2010), there is still debate on whether non-symbolic number comparison as well as symbolic number comparison performance relates to later mathematics. Whereas some researchers state it does (Halberda, Mazzocco, & Feigenson, 2008; Libertus, Feigenson, & Halberda, 2013; Mazzocco, Feigenson, & Halberda, 2011), others endorse only the contribution of symbolic number comparison (Bartelet, Vaessen, Blomert, & Ansari, 2014; Holloway & Ansari, 2009; Sasanguie, De Smedt, Defever, & Reynvoet, 2012; Sasanguie, Gobel, Moll, Smets, & Reynvoet, 2013). *Estimation* is often assessed using a number line task (Booth & Siegler, 2006; Siegler & Booth, 2004; Siegler & Opfer, 2003). Several studies indicated that the linearity of number line judgments is positively correlated with math achievement scores (Ashcraft & Moore, 2012; Siegler & Booth, 2004). Moreover, estimation accuracy (measured with mean percentages of error on the number line estimation task) has proven to be a unique predictor of mathematical achievement later on, next to the predictive role of linearity (Sasanguie et al., 2012; Sasanguie et al., 2013). Finally, *arithmetic operations* involve the ability to perform basic addition and subtraction transformation exercises (Purpura & Lonigan, 2013). Arithmetic operations, as part of a larger early numerical competencies battery, have proven to be predictive for later mathematical abilities, especially for applied problem solving (Jordan et al., 2010).

This short overview demonstrates that early numerical competencies are the first mathematical building blocks on which later mathematics is built (Berch, 2005; Geary, 2000; Jordan et al., 2010). However, two remarks should be made. On the one hand, a lot of studies incorporate only one of the early numerical competencies, relating it to one outcome score for mathematics (e.g., De Smedt et al., 2009; LeFevre et al., 2006; Siegler & Booth, 2004). On the other hand, many studies combine domain-specific and domain-general factors in one study, investigating the relative contribution of these categories without making a distinction between numerical competencies (Jordan, Kaplan, Locuniak, & Ramineni, 2007; Passolunghi & Lanfranchi, 2012; Traff, 2013). Moreover, in studies making this distinction, different early competencies are suggested as strong(est) predictors: counting and logical abilities (e.g., Stock, Desoete, & Roeyers, 2010), counting, verbal subitizing, and magnitude comparison (Praet, Titeca, Ceulemans, & Desoete, 2013), or arithmetic operations (operationalized through number combinations and story problems; Jordan, Kaplan, Ramineni, & Locuniak, 2009b). As such, there is no consensus regarding which of the early numerical competencies are most strongly associated with mathematical abilities in elementary school (Praet et al., 2013; Stock et al., 2010).

1.2 Mathematical Abilities in Elementary School Children

Although there is no unitary mathematical construct in elementary school (Dowker, 2005; Jordan, Mulhern, & Wylie, 2009a), several vital subcomponents are involved in adequate mathematical development. Difficulties in mathematics can manifest themselves on four domains: number sense, number facts, calculation or mathematical reasoning (APA, 2013). Whereas number sense can be considered as a low-level construct that is already present before formal schooling (Dehaene, 2001), the other three domains reflect "higher-order" or "secondary" abilities acquired through formal schooling (Geary, 2000). Dowker (2005) stated that *procedural calculation* is needed to solve arithmetic problems, converting numerical information into mathematical equations and algorithms. By executing arithmetic problems repetitively, basic number facts are retained in long-term memory and "automatically" retrieved if needed, termed as *number fact retrieval* (Dowker, 2005). Since some children might have problems in the area of procedural calculation whereas others have problems with automaticity and numerical facility (Jordan, Levine, & Huttenlocher, 1995), it is important to include both aspects in mathematics assessment. The domain of *mathematical reasoning* is associated with verbal problem solving abilities (Geary, Saults, Liu, & Hoard, 2000; Meyer, Salimpoor, Wu, Geary, & Menon, 2010). Over time, word problems or contextual problems have gained importance in the mathematics curriculum (Kilpatrick, Swafford, & Findell, 2001). Likewise, the role of language in mathematics was investigated more extensively (Hickendorff, 2013; Negen & Sarnecka, 2012; Praet et al., 2013). Recent research suggests that general language relates to early numeracy and that specific math language mediates this relationship (Toll, 2013), therefore suggesting the importance of assessing math language next to number facts and calculation. Finally, *time-related competences* are defined as the abilities associated with measuring or recording time and incorporate aspects such as clock reading, calendar use, and measuring of time intervals (Burny, Valcke, & Desoete, 2009). The concept of time is a complex construct, making it difficult to grasp by many children (Andersson, 2008; Burny et al., 2009). Given the particular difficulties of children with a mathematical learning disorder on this domain (Burny, Valcke, & Desoete, 2012), it should also be included when assessing mathematical abilities in elementary school.

Regarding the predictive value of preschool competencies for these mathematical outcomes in elementary school, it was not until recently that there is a growing emphasis on the use of a multicomponential approach in mathematics research in general (Jordan et al., 2009a). As such, only few studies have focused on different subcomponents or domains of mathematics as described above. The most investigated domains include number fact retrieval, calculation, and applied problems (e.g., Jordan et al., 2009b; Stock et al., 2010).

Most studies on mathematical abilities of children with ASD also fail to account for the componential nature of mathematics, providing only a single component score. The study of Iuculano et al. (2014) is the only one to conclude that children with ASD show a cognitive strength on numerical operations, while scoring in the average range for mathematical reasoning. Jones et al. (2009) assessed the same two components of mathematics in children with ASD. However, their conclusions (16.2% of the cases had a relative strength and 6.2% had a relative weakness in mathematics) were only based on the numerical operations subscale, as these authors wanted to assess arithmetic ability, presumed to be the most elementary form of mathematics and to be measured by the numerical operations subscale.

1.3 Objectives and Research Questions

Surprisingly few studies have been conducted to explore the combined effect of early numerical competencies in preschool on mathematics performance in first grade (Praet et al., 2013). The present study addresses this gap by investigating five early numerical competencies (verbal subitizing, counting, magnitude comparison, estimation, and arithmetic operations) as predictors of four domains of mathematics in first grade (procedural calculation, number fact retrieval, word/language problems, and time-related competences) in typically developing children and children with ASD. Although there is evidence for the predictive value of these early numerical competencies for later mathematics performance, there is little research tapping the relationship between all these numerical competencies simultaneously and first grade mathematics empirically with a longitudinal design.

The current study addresses three major research objectives. The first aim of the study was to compare children with ASD and TD children on early numerical competencies and on the domains of mathematics. Given the scarce and inconsistent results from previous studies, no specific hypotheses were postulated. The second aim of the study was to investigate the predictive value of the early numerical competencies for mathematics in first grade. Based on previous literature, one would expect to find all five numerical competencies to be predictive for mathematics performance one year later. It is, however, unclear which of the competencies would be most predictive. Moreover, the predictive value towards the different domains of mathematics was investigated more in detail. The third aim of the study was to investigate whether the results of children with ASD were similar to the pattern found in typically developing children. With no previous literature available on this topic, this study wanted to provide the first exploratory analysis of the predictive value of the five early numerical competencies in children with ASD.

2. Method

2.1 Participants and Procedure

Eighty-seven children (58 boys, 29 girls) were followed up from preschool to first grade. The early numerical competencies were assessed in the final year of preschool (mean age = 5.97, *SD* = 0.43), whereas the four domains of mathematics were assessed at first grade (mean age = 6.72, *SD* = 0.34).

Children with ASD (27 boys, 6 girls) were recruited through rehabilitation centers, special school services and other specialized agencies for developmental disorders; They had a formal diagnosis made independently by a qualified multidisciplinary team according to established criteria, such as specified in the DSM-IV-TR (APA, 2000). For all children, this formal diagnosis was confirmed by a score above the ASD cut-off on the Dutch version of the *Social Responsiveness Scale* (*SRS*; Roeyers, Thys, Druart, De Schryver, & Schittekatte, 2011). The Dutch version of the *SRS* has a good internal consistency, with a Cronbach's alpha of .94 for boys and .92 for girls (Roeyers et al., 2011). Scores on the *Autism Diagnostic Observation Schedule* (*ADOS*; Lord et al., 2000) were available for 21 children with ASD. Children with and without *ADOS*-scores did not differ significantly on the *SRS*.

In TD children (31 boys, 23 girls), there was no parental concern on developmental problems and all children scored below the ASD cut-off on the *SRS* (Roeyers et al., 2011).

Each participant had a full scale IQ (FSIQ) of 80 or more, measured with the *Wechsler Preschool and Primary Scale of Intelligence – Third edition* (*WPPSI-III*; Wechsler, 2002). As such, the study focused on a group of high-functioning children with ASD. Table 1 provides an overview of the sample characteristics.

< Insert Table 1 about here >

2.2 Measures

2.2.1 Early numerical competencies in preschool

2.2.1.1 Verbal subitizing

All children were tested with a computerized enumeration task (see Ceulemans et al., 2014; Praet et al., 2013), similar to the one described by Fischer, Gebhardt, and Hartnegg

(2008) and based on the stimuli of Maloney, Risko, Ansari, and Fugelsang (2010). Participants saw one to nine black square boxes and were instructed to say aloud the number of squares as quickly and accurately as possible. The individual area, total area, and density of the squares were varied to ensure that participants could not use non-numerical cues to make a correct decision (see Dehaene, Izard, & Piazza, 2005; Maloney et al., 2010). There were practice trials and a test phase, which consisted of 72 samples (each numerosity was presented eight times) with a presentation time of 120 ms, a mask of 100 ms and a total response time of 4,000 ms. This short presentation time prevented children from counting the squares (see Fischer et al., 2008). Cronbach's alpha was .88 for the subitizing range (1-3), .84 for the counting range (4-9), and .88 for the total range (1-9). The score on verbal subitizing was defined as the total accuracy score.

2.2.1.2 Counting

Counting was assessed using two subtests of the *Test for the Diagnosis of Mathematical Competencies* (*TEDI-MATH*; Grégoire, Noël, & Van Nieuwenhoven, 2004). The *TEDI-MATH* has proven to be conceptually accurate and clinically relevant and its predictive value has been demonstrated in several studies (e.g., Desoete et al., 2009; Stock, Desoete, & Roeyers, 2007). The procedural counting knowledge (subtest 1) was assessed using accuracy in counting row and counting forward to an upper bound and/or from a lower bound. The task had a maximum raw score of 8. The conceptual counting knowledge (subtest 2) was assessed by judging the validity of counting procedures, based on the five basic counting principles formulated by Gelman and Galistel (1978). Children had to count both linear and non-linear patterns of objects, and were asked some questions about it (e.g., "How many objects are there in total?"). Furthermore, they had to construct two numerically equivalent amounts of objects and use counting as a problem-solving strategy in a riddle. The maximum total raw score for this subtest was 13. The values for Cronbach's alpha ranged from .73 to .85. The score on counting was defined as the total accuracy score.

2.2.1.3 Magnitude comparison

A computerized magnitude comparison task (see Praet et al., 2013) was used in line with Halberda and Feigenson (2008) and Inglis, Attridge, Batchelor, and Gilmore (2011). In this task, two displays of black dots were presented simultaneously and participants were instructed to press the sun (leftmost) or moon (rightmost) button corresponding to the largest numerosity on a five-button response box as quickly and accurately as possible. Six different ratios were presented. When dividing the smallest by the largest numerosity, these ratios were: .33, .50, .67, .75, .80, and .83. The individual area, total area, and density of the squares were varied to ensure that participants could not use non-numerical cues to make a decision (see Dehaene et al., 2005). There were practice trials and a test phase, which consisted of 72 samples (each ratio was presented twelve times) with a presentation time of 1,200 ms, a mask of 2,800 ms and a total response time of 4,000 ms. Cronbach's alpha was .80 for the total task. The score on magnitude comparison was defined as the total accuracy score.

2.2.1.4 Estimation

A number line estimation task with a 0-100 interval was used, based on the procedure of Siegler and Opfer (2003). The task included 3 practice trials and 30 test trials. Stimuli were presented in a visual Arabic format (e.g., anchors 0 and 100, target number 3), an auditory verbal format (e.g., anchors zero and hundred, target number three), and an analogue magnitude format (e.g., anchors of zero dots and hundred dots, target number three dots). The dot patterns consisted of black dots in a white disc, controlled for perceptual variables using the procedure of Dehaene et al. (2005). Ten target numbers were selected: 2, 3, 4, 6, 18, 25, 42, 67, 71 and 86 (corresponding to sets A and B in Siegler & Opfer, 2003). Children were asked to put a single mark on the line to indicate the location of the number. Although the instructions could be rephrased if needed, no feedback was given to participants regarding the accuracy of their marks. The percentage absolute error (PAE) was calculated per child as a measure of children's estimation accuracy, following the formula of Siegler and Booth (2004). Cronbach's alpha was .87 for the total task. The score on estimation was defined as the total percentage of absolute error.

2.2.1.5 Arithmetic operations

Arithmetic operations were assessed using subtest 5.1 of the *TEDI-MATH* (Grégoire et al., 2004). A series of six visually supported addition and subtraction exercises were presented to the children (e.g., "Here you can see two red balloons and three blue balloons. How many balloons are there altogether?"). The maximum total raw score was 6. Cronbach's alpha of this subscale was .85. The score on arithmetic operations was defined as the total accuracy score.

2.2.2 Domains of mathematics in elementary school

2.2.2.1 Procedural calculation

The procedural calculation abilities of the children were tested using a subtest of the *Cognitive Developmental Skills in Arithmetics* (*Cognitieve Deelhandelingen van het Rekenen* [*CDR*]; Desoete & Roeyers, 2006). The *CDR* is a 90-item test that embraces different subskills, including procedural abilities (mathematical procedural problems, such as number splitting and addition/subtraction by regrouping, presented in a number problem format; e.g., “12 – 9 = __”; *P*). The *CDR* consists of three parallel test versions: grade 1-2, grade 3-4, and grade 5-6. In the current study, due to the age range of the children, the first version was used. Cronbach’s alpha was .74 for this subtest. The score on procedural calculation was defined as the total accuracy expressed as a z-score using the mean and standard deviation of the normed sample of the test.

2.2.2.2 Number fact retrieval

The *Arithmetic Number Facts Test* (*Tempotest Rekenen* [*TTR*]; De Vos, 1992) is a numerical facility test assessing the memorization and automatization of arithmetic facts. In first grade, two arithmetic number fact problem subtests are administered: addition and subtraction. Participants were instructed to solve as many items as possible in two minutes; they could work one minute on every subtest. Cronbach’s alpha for both subtests was .92. The score on number fact retrieval was defined as the total accuracy expressed as a z-score using the mean and standard deviation of the normed sample of the test.

2.2.2.3 Word/language problems

The word/language problem abilities were tested using three subtests of the *CDR* (Desoete & Roeyers, 2006): linguistic abilities (one-sentence mathematical problems in a word problem format; e.g., “1 more than 5 is__”; *L*), mental representation abilities (one-sentence mathematical problems that go beyond a superficial approach of keywords and that require a mental representation to prevent errors; e.g., “47 is 9 less than __”; *M*), and contextual abilities (more than one-sentence mathematical problems in a word problem format; e.g., “Wanda has 47 cards. Willy has 9 cards less than Wanda. How many cards does Willy have?”; *C*). As such, the word/language problems component was assessed by different subtests, incorporating aspects of simplicity (*L*) versus complexity (*C*) and items with (M) versus without (L) mental representation involved. Cronbach's alpha was .88 for all word/language problems. The score on word/language problems was defined as the total accuracy expressed as a z-score using the mean and standard deviation of the normed sample of the test.

2.2.2.4 Time-related competences

The Time Competence Test (*TCT*; *Test Tijdscompetentie*; Burny, 2012; Burny et al., 2012) is a test battery developed to assess the mastery of time-related competences in elementary school children. The test consists of four domains: clock reading, time intervals, time-related word problems, and calendar use. The *TCT* consists of four parallel tests that are associated with the ability levels in each grade (grade 1, grade 2, grade 3, and grade 4-6). The items are each time based on the Flemish elementary mathematics curriculum of the specific grade(s). The *TCT-1* includes 14 items. The *TCT* has been used to assess the time-related competences of Flemish elementary school children (Burny, 2012). Cronbach's alpha was .74. The score on time-related competences was defined as the total accuracy expressed as a z-score using the mean and standard deviation of the normed sample of the test.

2.3 Analyses

In a first step, a multivariate analysis of variance was used to compare the two groups of children on early numerical competencies in preschool, and on the domains of mathematics in elementary school. Moreover, both groups were not only compared to each other, but also to the normed population of the standardized tests in elementary school, in order to compare them to a reference point. To this end, all scores on the domains of mathematics were expressed as z-scores using the mean and standard deviation of the normed sample of the test. In order to be able to use a composite score, a general math index was created, which was calculated as the average z-score of all four domains of mathematics. A series of Bonferroni-corrected (p-value divided by four) one-sample t-tests was used to compare the z-scores of the four domains of mathematics against the normed samples.

Second, a Pearson correlation analysis was conducted to assess the linear relationships between the various early numerical competencies and the domains of mathematics in both TD children and children with ASD. In order to enable comparison with previous research that uses one single composite score, the general math index was included.

Finally, a multivariate regression analysis was conducted with the four domains of mathematics as outcome variables and the early numerical competencies as predictors. Group was included as factor to compare the TD children with the children with ASD. Starting from a model in which all five predictors, as well as all two-way interactions between the five predictors and the factor group were included, a backwards selection procedure was applied to reveal significant predictors. After describing this final model, FSIQ was added as a control variable in order to determine which effects remained significant after inclusion of this covariate. Other control variables were not included, since they did not significantly correlate with the outcome variables in both groups ($p > .050$). All analyses were performed in SPSS Version 21.0 (IBM Corp., 2012).

3. Results

3.1 Comparison of TD Children and Children with ASD

A multivariate analysis of variance indicated no significant differences in early numerical competencies at preschool age between the two groups, $F(5, 81) = 1.17$, $p = .330$ (see Figure 1). However, there was a significant difference between TD children and children with ASD for the domains of mathematics in first grade, $F(4, 82) = 4.45$, $p = .003$, with TD children scoring higher than the children with ASD. This difference remained significant even after controlling for FSIQ (this control variable was significantly related to the scores on the domains of mathematics), $F(4, 80) = 2.78$, $p = .032$. When looking at the univariate test results, there was only a significant difference for the domains of number fact retrieval and word language problems, $F(1, 83) = 4.44$, $p = .038$ and $F(1, 83) = 8.18$, $p = .005$ respectively. Children with ASD obtained lower scores on these domains compared to the TD children (see Figure 2).

When comparing the children with ASD to the normed samples of the tests, the children with ASD turned out to score higher than the normed samples for the general math index, $t(32) = 3.54$, $p = .001$. The same pattern of results held for the domains of procedural calculation and word/language problems, $t(32) = 4.19$, $p < .001$, and $t(32) = 4.07$, $p < .001$ respectively (see Figure 3). After applying a Bonferroni correction, there was no significant difference between the ASD group and the normed samples for the domains of number fact retrieval and time related competences, $t(32) = 2.09$, $p = .044$ and $t(32) = 1.83$, $p = .076$ respectively (see Figure 3).

3.2 Bivariate Relations among The Constructs

Table 2 provides the correlation matrix of the early numerical competencies in preschool, the general math index in elementary school, the four separate domains of mathematics, and FSIQ in both TD children and children with ASD.

< Insert Table 2 about here >

Early numerical competencies are closely interrelated in both groups of children, mostly showing significant correlations. The domains of mathematics also intercorrelate significantly, with positive values for all. Significant correlations can be found between early numerical competencies and both the general math index, and the domains of mathematics separately. Overall, correlations for TD children and children with ASD show a similar pattern, but in some instances the correlations in the ASD group are significantly stronger compared to TD children. This can be observed for some correlations between verbal subitizing or counting and later mathematics, as well as for some intercorrelations between the domains of mathematics (Fisher r-to-z transformations, $p < .050$; see Table 2).

3.3 Predictive Value of Early Numerical Competencies for Later Mathematics

A multivariate regression analysis was conducted with the four domains of mathematics as outcome variables. Starting from a model in which all five predictors as well as the two-way interactions between the five predictors and group were included, a backwards selection procedure revealed the following significant predictors at multivariate level: verbal subitizing, $F(4, 79) = 5.23$, $p = .001$; counting, $F(4, 79) = 2.62$, $p = .041$; and verbal subitizing x group, $F(4, 79) = 3.14$, $p = .019$. The significant intercorrelations between predictors imposed no problem for multicollinearity, as all VIF-values were close to 1 (Field, 2009).

At the univariate level, there was a significant effect of verbal subitizing on procedural calculation, number fact retrieval and word/language problems, $F(1, 82) = 6.74$, $p = .011$, $F(1, 82) = 16.67$, $p < .001$, and $F(1, 82) = 5.62$, $p = .020$ respectively. This term resulted in on average higher scores in the outcome variables procedural calculation, number fact retrieval and word/language problems, with increasing values for verbal subitizing. However, there was also a significant effect of the verbal subitizing x group interaction on number fact retrieval, $F(1, 82) = 11.32$, $p = .001$, resulting in a differential effect of verbal subitizing on number fact retrieval for both groups: Whereas verbal subitizing was a significant predictor for number fact retrieval in the ASD group, $t(83) = 4.58$, $p < .001$, it was not for the TD children, $t(83) = 0.02$, $p = .311$. For counting, there was a significant positive effect on procedural calculation, $F(1, 82) = 6.31$, $p = .014$, word/language problems, $F(1, 82) = 5.34$, $p = .023$, time-related competences, $F(1, 82) = 4.59$, $p = .035$, and a trend for number fact retrieval, $F(1, 82) = 3.88$, $p = .052$. Higher values of counting were associated with on average higher values for the outcome variables. Table 3 provides an overview of the estimated regression coefficients and the standard errors of the model.

In a next step, FSIQ was added as a control variable to the model, since it correlated significantly with the outcome variables (see Table 2). After controlling for FSIQ, the effects of verbal subitizing on the different domains of mathematics remained unchanged. There still was a significant positive effect of verbal subitizing on procedural calculation and word/language problems, with $F(1, 80) = 5.43$, $p = .022$ and $F(1, 80) = 5.20$, $p = .025$ respectively. There also remained an effect of verbal subitizing on number fact retrieval for the ASD group, $t(82) = 4.33$, $p < .001$. For counting, the positive effects on procedural calculation and number fact retrieval remained unchanged, with $F(1, 80) = 5.09$, $p = .027$ and $F(1, 80) = 3.00$, $p = .087$ respectively. However, the effect of counting on word/language problems and time-related competences disappeared when taking into account FSIQ, $F(1, 80) = 2.14$, $p = .147$ and $F(1, 80) = 2.25$, $p = .122$ respectively. An overview of the estimated regression coefficients and the standard errors of the model with FSIQ included can be found in Table 4.

4. Discussion

The current study aimed at investigating the predictive value of five early numerical competencies at preschool age for four domains of mathematics in first grade. Since previous research comparing the mathematical abilities of children with ASD and typically developing children is scarce (and even unexplored at preschool age), the current study compared the performance of the two groups of children both at preschool age and in first grade in a first step. Next, it was investigated which of the early numerical competencies were most predictive for first grade mathematics performance, differentiated into four domains of mathematics, in typically developing children and children with ASD.

4.1 General Findings

The current study compared the five early numerical competencies as outlined in the review of Jordan and Levine (2009), in typically developing children and children with ASD at preschool age (5-6 years). Results revealed no significant differences between the two groups of high-functioning preschoolers, suggesting a similar early number processing in children with and without ASD at this young age. This finding is in line with some previous studies that investigated mathematical abilities in children with ASD from a between-group perspective, but at a later age (Chiang & Lin, 2007; Gagnon et al., 2004; Iuculano et al., 2014; Jarrold & Russell, 1997).

In contrast, when comparing both groups of children in first grade, children with ASD obtained significantly lower scores on the domains number fact retrieval and word/language problems than typically developing peers, even after controlling for FSIQ. This finding seems to undo the aforementioned similarity with previous research on the topic. However, when comparing the ASD group to the normed samples of the test, the children with ASD appeared to score average on the domains of number fact retrieval and time-related competences, and significantly higher on the domains of procedural calculation and word/language problems. In this way, the current results are consistent with previously reported average to good mathematical abilities of children with ASD compared to the normed population (Chiang & Lin, 2007; Church, Alisanski, & Amanullah, 2000). A likely explanation for the mathematical proficiency of both the typically developing children and the children with ASD is the selective sample of the current study, as indicated by the values on FSIQ and socio-economic status (which are significantly higher than in the general population). The descriptive characteristics of the sample suggest the inclusion of high-functioning children with a high socio-economic (SES) background, probably resulting in more learning opportunities and numerical stimulation (Jordan, Kaplan, Olah, & Locuniak, 2006; Melhuish et al., 2008). Indeed, parental social class and educational level have proven to be predictive for mathematics achievement (Jordan & Levine, 2009). The fact that no significant correlations were found between SES and early numerical competencies or domains of mathematics in our sample, could be due the inclusion of this upper bound SES group, leading to a lack of variation in scores.

Results of the correlation matrix show that the five early numerical competencies are frequently significantly intercorrelated in the expected direction (positive when both competencies are positively operationalized and negative with estimation, which is operationalized as a percentage of error). The domains of mathematics also show significant positive interrelations. Moreover, all five early numerical competencies show an expected pattern of correlations with the domains of mathematics. The highest correlations can be observed for counting and arithmetic operations in both groups and for verbal subitizing in the ASD group.

This pattern of results was somehow reflected in the multivariate regression analysis, presenting both counting and verbal subitizing as important predictors for mathematics performance in first grade in both groups of children. Whereas verbal subitizing was the strongest predictor for mathematics in the ASD group, counting was the strongest predictor in typically developing children. Arithmetic operations tested in preschool did not have a significant unique contribution to later mathematics over and above verbal subitizing and counting, perhaps because at this young age, almost all children use counting strategies to solve this simple addition and subtraction exercises (Baroody, 1987; Butterworth, 2005). Before children learn number facts that can be retrieved from long-term memory, they rely on counting procedures to solve these problems (Fuchs et al., 2009).

The univariate tests of the regression analysis allowed us to interpret the results of our multicomponential approach. In children with ASD, verbal subitizing was the strongest predictor for all domains of mathematics, except for time-related competences. In typically developing children, verbal subitizing was only predictive for procedural calculation and word/language problems, and with a smaller predictive value than counting. The stronger predictive value of verbal subitizing in children with ASD could perhaps be due to the importance of perceptual characteristics in this task, since children with ASD are known to show an enhanced perceptual functioning (Mottron, Dawson, Soulieres, Hubert, & Burack, 2006). Although not causing a superior performance on verbal subitizing, the task could be more appealing to children with ASD. It is likely that children with ASD use different strategies or cues when solving tasks, which may be in turn more related to their strategy use in later mathematics (Gagnon et al., 2004; Iuculano et al., 2014; Jarrold & Russell, 1997).

Although counting was a significant predictor of later mathematics performance in both groups of children, the predictive value of counting was stronger in typically developing children. The predictive value of counting is in line with some previous studies that presented counting as a key precursor for later mathematics performance (Aunola et al., 2004; Desoete et al., 2009; Stock, Desoete, & Roeyers, 2009; Stock et al., 2010). At first, counting seemed to be a good predictor for all domains of mathematics when investigated at first grade. However, when controlling for FSIQ, counting was most predictive for procedural calculation and in less extent (showing only a marginally significant result) for number fact retrieval. Both domains of mathematics are operationalized in a similar way, providing addition and subtraction exercises in a number problem format. As such, it seems logical to observe parallels between these exercises since they are closely linked. However, whereas number fact retrieval consists of timed basic arithmetic facts easily retrieved from long-term memory, procedural calculation requires the use of procedures and computational strategies such as number splitting and addition/subtraction by regrouping to solve the task at hand and are untimed (Domahs & Delazer, 2005). As such, children may be in need of counting procedures when acquiring the skills to solve procedural tasks and only favor memory-based retrieval of answers after increasingly efficient counting and decomposition strategies help them to establish associations in long-term memory (Fuchs et al., 2009; Koponen, Aunola, Ahonen, & Nurmi, 2007). Due to the untimed character of the test, the exercises may evoke more counting strategies then when working under time restraints. Most previous research investigating the predictive value of counting uses one composite math score, not allowing us to differentiate between different domains of mathematics (e.g., Aunio & Niemivirta, 2010; Aunola et al., 2004; Stock et al., 2010). However, a relationship between counting and either timed or untimed calculation performance has already been demonstrated (e.g., Geary, Bowthomas, & Yao, 1992; Johansson, 2005; Koponen et al., 2007).

4.2 Strengths and Limitations

This study adds to the scarce literature on mathematical abilities in children with ASD, not only by comparing the mathematical abilities at elementary school age, but also by taking into account the early numerical competencies at preschool level. Moreover, this study is the first to investigate the predictive value of early numerical competencies measured at preschool age for mathematics performance in first grade in a group of children with ASD, allowing us to gain insight into this important transition period. In this way, the current study goes beyond comparing the abilities of two groups of children, but points towards possible differences in processes or cues used to perform mathematical tasks.

The current study used a multicomponential approach on the predictors as well as on the outcome variables, whereas previous research focused on one single aspect of mathematics or applies one composite math score. Recent research emphasized the importance of incorporating such a multicomponential approach and strongly advocates this in future research (Jordan et al., 2009a; Mazzocco, 2009; Simms, Cragg, Gilmore, Marlow, & Johnson, 2013).

However, some limitations should be borne in mind when interpreting the results of the current study. First, the current study includes a substantially smaller sample size compared to previous studies investigating the predictive value of multiple early numerical competencies (e.g., Jordan et al., 2007; Jordan et al., 2009b; Stock et al., 2009, 2010). Although these studies indeed incorporate a much larger sample, we should be aware of the fact that only typically developing children are included. The sample size of the current study is however comparable with other studies on mathematics including the clinical group condition of ASD (e.g., Gagnon et al., 2004; Iuculano et al., 2014; Jarrold & Russell, 1997).

Nevertheless, the smaller sample size could result in a decreased probability to detect possible predictors or interactions between the predictors and group condition. This probability was also diminished by the multicomponential approach for both predictors and outcomes, leading to a model in which many variables are included. Second, the current study includes a highly selective sample, with only high-functioning children with ASD. Moreover, both groups proved to show high scores on FSIQ and SES, suggesting that perhaps mostly well-educated and highly motivated parents decided to participate to the study. This sample selection bias puts limits to the generalizability of the findings to lower functioning children with a lower socio-economic background. Finally, it is important to note that most of the instruments have never been used in an ASD group before. However, standardized measures already validated in typically developing children were used whenever possible. The experimental tasks were operationalized similar to previous research on this topic, resulting in similar effects ("elbow effect" for the subitizing task, ratio-dependency for the magnitude comparison task, similar PAE scores for the number line estimation task). All experimental measures were used in typically developing populations or children with MLD in previous research (e.g., Berteletti, Lucangeli, Piazza, Dehaene, & Zorzi, 2010; Ceulemans et al., 2014; Praet et al., 2013; Stock et al., 2007).

4.3 Implications and Conclusion

Based on the results of the current study, mathematics should not be a concern in children with ASD, at least when having higher than average FSIQ and SES scores. At preschool age, the children with ASD score similar on early numerical competencies to the typically developing children included in the study. At first grade, our ASD group scored significantly lower on the four domains of mathematics than the typically developing group, but average to high compared to the normed samples of the tests. Therefore, it can be concluded that the foundation of mathematical development in high-functioning children with ASD stemming from a high socio-economic background might be similar to that of typically developing peers in general.

When trying to predict the mathematical abilities of children with ASD from preschool age, our result suggest that a test battery should at least include a verbal subitizing task and a counting task. Bearing in mind our specific high-functioning group with well-educated and well-employed parents, these variables are most predictive for mathematics in first grade for this group of children. Future research should investigate whether these predictions hold at later age as well, or whether these precursors are only predictive for initial mathematics achievement in first grade. This is especially the case for counting which is an important antecedent in the development of calculation strategies (Johansson, 2005), but only as an early solution procedure which facilitates the formation of associations in long-term memory between the problem presented and the answer. Over time, new and more accurate fact retrieval strategies are used for solving arithmetic problems (Johansson, 2005). Regarding verbal subitizing, future research should investigate more in detail why this ability is particularly predictive for first grade mathematics in children with ASD.

To conclude, no concerns should be raised over the mathematical abilities of high-functioning children with ASD with a high socio-economic background in general, since these children score on group level comparable or even higher than the general first-grade population. This finding does, however, not detract from the importance of individual assessment and evaluation in the classroom. When trying to predict later mathematical performance in first grade, both counting and verbal subitizing seem to be important predictors to evaluate and to incorporate in an assessment battery at preschool age. However, whereas counting is most informative in typically developing children, verbal subitizing is most predictive in children with ASD.

5. Acknowledgements

This work was supported by the Ghent University Research Fund (BOF) [grant number BOF10/DOC/248]. This funding source had no further involvement in the conduct of the current research project. All participating children and parents are thanked.

6. Conflict of Interest Statement

The authors state no conflict of interest in the current study.

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Table 1

Descriptive characteristics of the sample.

	TD (n = 54)		ASD (n = 33)		
	Mean	(*SD*)	*Mean*	(*SD*)	
Age T1 (in years)	5.79	(0.35)	6.27	(0.38)	$t(85) = -5.96, p < .001$
Age T2 (in years)	6.63	(0.34)	6.87	(0.29)	$t(85) = -3.32, p = .001$
FSIQ[a]	111.44	(11.93)	105.38	(13.27)	$t(84) = 2.19, p = .032$
VIQ	112.26	(11.32)	105.09	(13.50)	$t(84) = 2.64, p = .010$
PIQ	107.15	(11.79)	106.06	(15.07)	$t(84) = 0.37, p = .711$
SES[b]	50.47	(7.49)	47.03	(9.04)	$t(85) = 1.92, p = .058$
SRS (T-score)[c]	47.89	(5.56)	85.79	(19.10)	$t(35.35) = -11.12, p < .001$

Note. TD = typically developing children; ASD = children with autism spectrum disorder. [a]Full Scale IQ, measured with *Wechsler Preschool and Primary Scale of Intelligence – Third edition*; [b]Socio-economic status, measured with Hollingshead Index; [c]T-score on *Social Responsiveness Scale*.

Table 2

Correlations between early numerical competencies, domains of mathematics, and Full Scale IQ.

		Verbal subitizing	Counting	Magnitude comparison	Estimation	Arithmetic operations	General math index	Procedural calculation	Number fact retrieval	Word/ language problems	Time-related competences	FSIQ
Verbal subitzing	**TD**	-										
	ASD	-										
Counting	**TD**	**.39*** **	-									
	ASD	.59****	-									
Magnitude comparison	**TD**	**.38*** **	**.18**	-								
	ASD	.34*	.34**	-								
Estimation	**TD**	**-.44*** **	**-.31** **	**-.28** **	-							
	ASD	-.45**	-.34*	-.41**	-							
Arithmetic operations	**TD**	**.28** **	**.47**** **	**.18**	**-.28** **	-						
	ASD	.50***	.53***	.14	-.24	-						
General math index	**TD**	**.29** **	**.44*** **	**.31** **	**-.29** **	**.38*** **	-					
	ASD	.68****	.58****	.35**	-.37**	.42***	-					
Procedural calculation	**TD**	**.21**	**.39*** **	**.08**	**-.30** **	**.15**	**.70**** **	-				
	ASD	.60****	.46***	.15	-.43**	.35**	.82****	-				
Number fact retrieval	**TD**	**.23**	**.39*** **	**.32** **	**-.24* **	**.28** **	**.73**** **	**.36*** **	-			
	ASD	.73****	.46***	.38**	-.43**	.35**	.89****	.70****	-			
Word/language problems	**TD**	**.23**	**.30** **	**.18**	**-.12**	**.34** **	**.64**** **	**.31** **	**.18**	-		
	ASD	.54***	.50***	.35**	-.32*	.40**	.83****	.60****	.61****	-		
Time-related competences	**TD**	**.11**	**.09**	**.26* **	**-.11**	**.29** **	**.66**** **	**.26* **	**.26* **	**.40*** **	-	
	ASD	.30*	.51***	.22	.03	.29*	.73****	.41**	.47***	.63****	-	
FSIQ	**TD**	**.13**	**.15**	**.32** **	**-.34** **	**.27** **	**.35*** **	**.23* **	**.15**	**.34** **	**.30** **	-
	ASD	.35**	.50***	.24	-.23	.36**	.51***	.42**	.43**	.59****	.28	-

Note. TD = typically developing children; ASD = children with autism spectrum disorder; FSIQ = full scale IQ

* *p* < .10, ** *p* < .05, *** *p* <.01, **** Bonferroni-corrected (*p* < .001); underlined correlations indicate a significantly higher correlation than in the other group (Fisher r-to-z transformation, *p* < .050)

Table 3

Estimated standardized regression coefficients and standard errors for the multivariate regression model without Full Scale IQ.

		TD (n = 54)		ASD (n = 33)	
		β	± *SE*	β	± *SE*
Procedural calculation	Verbal subitizing	.09	±.12	.47	±.17
	Counting	.27	±.11	.27	±.11
Number fact retrieval	Verbal subitizing	.16	±.15	.99	±.22
	Counting	.27	±.14	.27	±.14
Word/language problems	Verbal subitizing	.10	±.11	.37	±.15
	Counting	.22	±.10	.22	±.10
Time-related competences	Verbal subitizing	.00	±.12	.15	±.17
	Counting	.23	±.11	.23	±.11

Note. TD = typically developing children; ASD = children with autism spectrum disorder.

Table 4

Estimated standardized regression coefficients and standard errors for the multivariate regression model with Full Scale IQ as control variable.

		TD (n = 54)		ASD (n = 33)	
		β	± *SE*	β	± *SE*
Procedural calculation	Verbal subitizing	.08	±.12	.42	±.17
	Counting	.24	±.11	.24	±.11
Number fact retrieval	Verbal subitizing	.15	±.15	.95	±.22
	Counting	.24	±.14	.24	±.14
Word/language problems	Verbal subitizing	.09	±.10	.33	±.14
	Counting	.13	±.09	.13	±.09
Time-related competences	Verbal subitizing	.17	±.11	.13	±.11
	Counting	.17	±.19	.27	±.19

Note. TD = typically developing children; ASD = children with autism spectrum disorder.

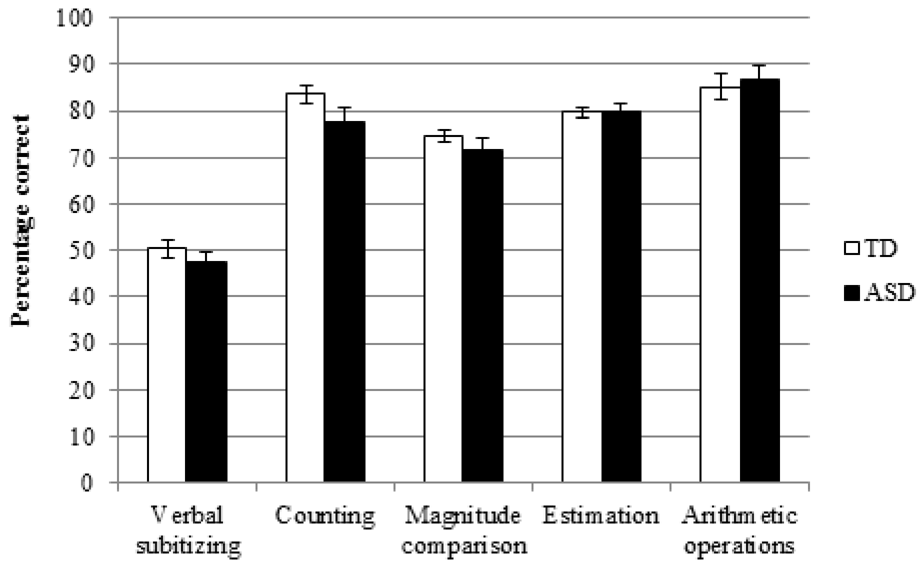

Figure 1. Early numerical competencies for typically developing children and children with autism spectrum disorder.
TD = typically developing children; ASD = children with autism spectrum disorder.

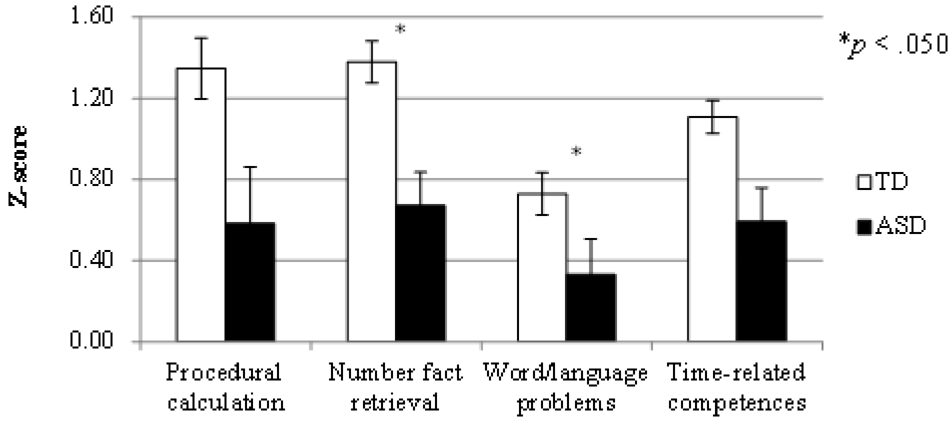

Figure 2. Domains of mathematics for typically developing children and children with autism spectrum disorder.
TD = typically developing children; ASD = children with autism spectrum disorder.

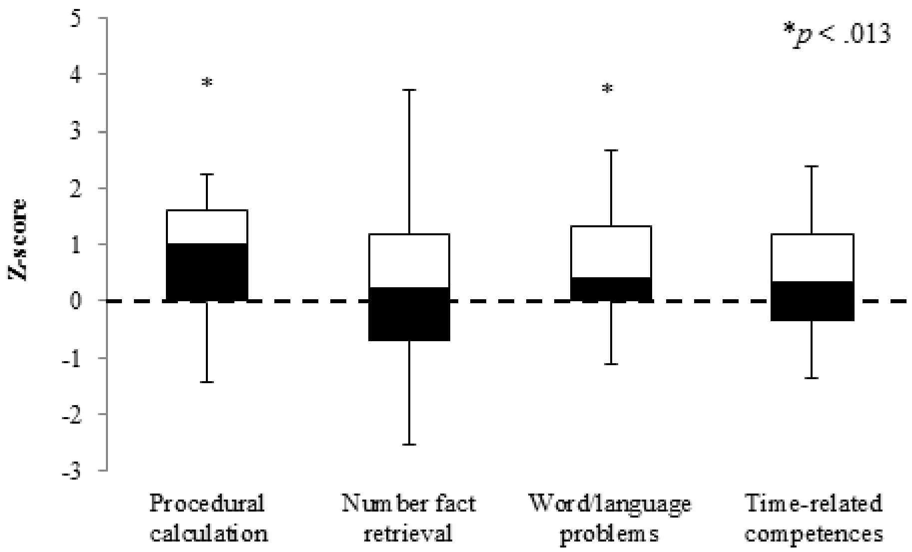

Figure 3. Domains of mathematics for children with autism spectrum disorder compared to the normed population.